Maize Resistance to the Lesser Cornstalk Borer and Fall Armyworm In Brazil

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Abstract

Maize, Zea mays, is an important cereal crop in Brazil. It is extensively grown throughout the country for food grain, feed, and fodder purposes. Among many factors, insects pests play a major role in limiting maize yields. The lesser cornstalk borer (LCB) and the fall armyworm (FAW) have been considered the most important field pests, being key pests in many of the areas where the crop is grown. The FAW and the LCB have been reared at EMBRAPA/CNPMS to undertake artificial infestation for large-scale studies, including screening for resistance. Several genetic materials were selected for resistance. Sources of resistance such as CMS 23 and CMS 24 to FAW, CMS 15 and CMS 454 to LCB are being used in breeding for resistance. The resistance mechanisms to FAW were studied on four selected maize genotypes. Larvae reared on CMS 14C required longer to develop to the pupal and adult stages and had reduced larval and pupal weights. The genotype Zapalote Chico had fewer larvae feeding on leaf sections than other genotypes tested. The analysis of a diallel cross indicated that gene action conditioning resistance to the FAW appears to be due to additive and non-additive effects.

Introduction

Maize, *Zea mays*, is an important cereal crop in Brazil. It is extensively grown throughout the country for food grain, feed, and fodder purposes. The total area under cultivation in the country during 1992-93 was 11.2 million hectares, with a production of 26.8 million tons of grain, an average yield of 2.4 t/ha (Carrieri et al. 1993).

In Brazil, among many factors, insect pests play a major role in limiting maize yields. A list of insects attacking maize in Brazil is shown in Table 1.

Among the insects attacking maize, the fall armyworm (FAW), *Spodoptera frugiperda* and the lesser cornstalk borer (LCB), *Elasmopalpus lignosellus* have been considered the most important field pests, being key pests in many of the areas where maize is grown.

Damage and Economic Importance

The FAW larvae attack maize at all stages, although the most serious damage occurs at the mid-whorl stage (Cruz 1980). According to Carvalho (1970), depending on the stage of the plant when the damage is done, the yield reduction ranges from 15 to 34%.

Table 1. Insects damaging maize in Brazil.

Scientific name	Common name	Pest status
Spodoptera frugiperda	Fall armyworm	***
Elasmopalpus lignosellus	Lesser cornstalk borer	***
Sitophilus sp	Weevils	***
Helicoverpa zea	Corn earworm	**
Diabrotica speciosa	Corn rootworm	**
Diatraea saccharalis	Sugarcane borer	**
Mocis latipes	-	*
Agrotis ipsilon	Black cutworm	*
Rhapalosiphum madis	Corn leaf aphid	*
Deois flavopicta	Leaf hoppers	*
Scaptocoris castanea	-	*
Sitotroga cerealella	Angoumois grain moth	*
Several species	Wireworms	*
Several species	White grubs	*

*** Key pest; ** occasional; * secondary

The LCB larva is a semi-subterranean feeder, usually attacking a seedling plant at or just below the soil surface. Larvae bore into the stem and during feeding, produce tunnels upward and downward from the entrance hole. Feeding usually kills the young plant. According to All et al. (1982), when plants are killed and desiccated, LCB larvae move to adjacent plants. Several plants may be killed by one larva in this way. Damage caused by this insect is reported to be from 20 to 50% of the planted area (Sauer 1939; Viana 1991) or even the entire crop (Jacobsen 1928).

Techniques for Mass Rearing, Artificial Infestations and Evaluation Procedures

The Maize and Sorghum National Research Center/EMBRAPA at Sete Lagoas, MG, Brazil, has mass reared FAW and LCB since the early 1980s, enabling the Institute to undertake artificial infestation for large-scale studies — including screening for resistance and developing biological, cultural and chemical control tactics for pest management programs.

Fall armyworm

The FAW is reared at EMBRAPA/CNPMS on a modified black cutworm diet described by Reese et al. (1972) (Table 2). The moths lay eggs on paper napkins, placed into a oviposition cage (62 x 62 cm), which are cut into strips and placed in plastic jelly cups to be incubated at 28° C. After incubation, one small larva is transferred to an individual plastic jelly cup, containing the diet, and then sealed with flexiglas lids. The cups are placed into trays that hold 32 cups and are kept undisturbed until adult emergence. The adults are transferred daily from cups to oviposition cages and are fed with sugar solution through a cotton wick in a 50 ml plastic jelly cup. Recently, we are testing split cell modules placed into the boxes (29 x 29 x 4 cm), as used at CIMMYT and described by Mihm (1989a), to rear FAW larvae.

Artificial infestation with FAW is done at EMBRAPA/CNPMS at the 4 to 5 fully expanded leaf stage. The technique used is similar to that described in detail by Mihm (1989b). The larval infestation of every plant to be screened is done with 30-40 hatched larvae mixed with maize cob grits, using a "bazooka" to deliver the neonate larvae into the plant whorl. Evaluation for resistance to leaf feeding is made 14 days after infestation using a visual leaf feeding damage scale varying from 0 to 9 as suggested by Davis and Williams (1989). For an initial screening of materials we usually plant one 10 m row where half of each row is protected with insecticide. Two replications are usually planted.

Table 2. Ingredients for the FAW diet used at EMBRAPA/CNPMS.

Ingredients	Amount
Pinto beans	333.0 g
Torula yeast	101.4 g
Wheat germ	158.4 g
Ascorbic acid	10.2 g
Methyl p-hidroxy benzoate	6.3 g
Sorbic acid	3.3 g
Agar	41.0 g
40% Formalin	8.3 ml
Water	2400.0 ml

Table 3. Ingredients for the LCB diet used at EMBRAPA/CNPMS.

Ingredients	Amount
Agar	40 g
Water	1280 ml
Pinto bean	420 g
Water (hot)	1300 ml
Yeast	128 g
Wheat germ	200 g
Mold inhibitor	10 ml
Ascorbic acid	13 g
Methyl paraben	8 g
Sorbic acid	4 g
40% formalin	8 ml
55% linolenic acid	10 ml
Tetracycline	1 capsule (250 mg)
Vanderzaant's vitamin mixture	5 g
Mold inhibitor ingredients	
Propionic acid	418 ml
Phosphoric acid (conc.)	42 ml
Water (dist.)	540 ml

Lesser cornstalk borer

A modificiation of Burton's (1969) pinto bean diet cited by Chalfant (1975) (Table 3) is used to rear LCB larvae at EMBRAPA/CNPMS. The moths lay eggs singularly on napkins placed on the top and bottom of the oviposition cage (cylinder of 20 cm diam. x 20 cm). Napkins with eggs are placed inside a small plastic bag and kept at 28° C until hatch. Newly hatched larvae are mixed with fine (# 4) vermiculite and poured into plastic jelly cups containing diet. Larvae average 3 to 5 per cup using this method. Preformed trays holding 32 cups, are left undisturbed until adult emergence. The number of adults per oviposition cage is 30 pairs. The adult food (beer) is supplied through 4 medicine droppers inserted in the middle of the oviposition cage. The oviposition cage is maintained at 28° C with a 16 hour photoperiod.

Screening trials to evaluate maize germplasm for LCB resistance are conducted in the greenhouse. Ten maize seeds are planted in 5 L plastic pots. When the seedlings emerge, each pot is infested with 50 eggs. Plants attacked, number larvae alive and weight of larvae are recorded 15 days after infestation.

Genetic Sources of Resistance and Breeding Methodologies

In the mid-1980s research was intensified by EMBRAPA/CNPMS, with a large amount of indigenous and exotic germoplasm and elite lines being tested for resistance to FAW and LCB. The screening work identified several sources of resistance to these insect pests (Viana 1992a; 1992b). The materials selected are presented in

Tables 4 and 5. During the last 8 years, many maize genotypes were infested and the subsequent leaf damage and percentage of plants alive were evaluated for resistance to FAW and LCB, respectively. Some material that appeared to sustain less damage than others and showed good agronomic traits was selected for breeding for resistance. Sources of resistance such as CMS 23 and CMS 14C to FAW, CMS 15 and CMS 454 to LCB are being used in breeding for resistance.

A recurrent selection scheme and mass selection have been used to accumulate desirable genes for resistance to the FAW and LCB, respectively. A summary of the procedures of selection for resistance against these pests at EMBRAPA/CNPMS is presented in Table 6.

Mechanisms and Inheritance of Resistance

The resistance mechanisms to FAW have been studied in the laboratory, greenhouse and field at EMBRAPA/CNPMS. Four maize genotypes, CMS 23, CMS 14C, CMS 24 and Zapalote Chico were selected for study in the laboratory and greenhouse. Larvae reared on CMS 14C required longer to develop to the pupal and adult stages. Also, larvae reared on leaf tissue of CMS 14C presented reduced larval and pupal weights.

Both choice and non-choice tests were used to determine if resistant genotypes were less preferred by the larvae for

Table 4. Maize genotypes selected for resistance to FAW at EMBRAPA/CNPMS.

Year	Genotypes	Damage range	Mean ratings
1986/87	CMS 23		4.0
	CMS 14C		5.4
	CMS 24		5.5
	Zapalote Chico	4.0 to 7.5	5.5
1987/88	CMS 23		4.9
	CMS 24		4.9
	Zapalote Chico		4.1
	CMS 456		5.0
	BA 03		5.2
	SE 20		5.3
	CMS 451		5.4
	SE 14		5.5
	CMS 467	4.1 to 7.2	5.5
1988/89	Amarillo Cristalino		1.1
	WP 1		1.1
	RR 060		1.4
	MG 05	1.1 to 3.7	1.5
1989/90	BR 108 Tuxpeño		5.5
	Comp. Tuxpeño Veracruzano		5.4
	Mata Hambre X Guajira 314		5.5
	Nõdzob Torê		4.8
	Oaxaca 250		5.5
	Puerto Rico 5		5.0
	WP 33		5.5
	Cuba 45		5.5
	WP 18		5.4
	Zapalote Chico	4.8 to 7.0	5.3
1990/91	077 R2		2.2
	Guatemala 786		2.5
	Nõdzob Prê		2.5
	Puerto Rico 13		2.5
	Composto Arco Iris		2.5
	Guatemala 73		2.5
	139 R2	2.2 to 5.5	2.5
1991/92/93	PB 11		4.4
	WP 16		4.8
	Rep.Dominicana 248		5.2
	Zapalote Chico		5.3
	BA 22		5.5
	PA 008	4.4 to 7.0	5.5

Table 5. Maize genotypes selected for resistance to LCB at EMBRAPA/CNPMS.

Year	Genotypes	Damage range	Plants attacked (%)
1986/87	CMS 454		42
	CMS 15		42
	Baier		50
	Zapalote Chico	42 to 100	50
1987/88	RN 01		50
	BA III Tucson	50 to 100	50
1988/89	BA 60		50
	Guadeloupe 16		50
	SE 10	40 to 100	50
1989/90	CMS 472		30
	Jalisco 274	30 to 100	50
1990/91	Cateto Colômbia VII		40
	Cohauila 56		50
	CMS 15	40 to 100	50
1991/92	PB 13		40
	Zapalote Chico		42
	PAG VI - Moroti		45
	EW 3151 V.S.C.	40 to 100	54
1992/93	AC 84		45
	Centralmex J-VIII		45
	Composto Jaíba IV		45
	Cateto Prolífico IX		50
	Composto Cerrado I		50
	PB 11	45 to 100	50

Table 6. Schemes of selection for resistance used to FAW and LCB at EMBRAPA/CNPMS.

Population	Pest	Breeding methods	Year	Number of progenies screened	Number of progenies selected	Cycles of selection (1994)
CMS 14C	FAW	FS-S_1	87/88	200	20	4
CMS 23	FAW	Inbreeding Synthetics	88/89	200	20	1
MIRT	FAW	FS-S_1	91/92	180	35	2
CMS 15/ CMS 454	LCB	Mass Sel.	90/91	1000	128	3

feeding than susceptible genotypes. The results demonstrated that the genotype Zapalote Chico had fewer larvae preferring to feed on leaf sections than other genotypes tested. An additional test was conducted to determine adult oviposition preference using the same genotypes. The genotype CMS 14C was less preferred for oviposition compared with the remaining genotypes.

A tolerance study was conducted in yield trials where performance under both infested and protected split plots was evaluated. The results presented in Table 7 show a few materials indicating some tolerance to FAW leaf feeding damage.

We have conducted only limited investigations into the inheritance of leaf-feeding resistance to the FAW. The analysis of a diallel cross of 10 populations (Table 8) grown under artificial infestation indicated that both general and specific combining ability were significant sources of variation (Guimarães and Viana 1994). Gene action conditioning resistance to FAW appears to be due to additive and non-additive effects. The mean ratings of FAW damage on the 0 to 9 scale were 2.5 for crosses of resistant populations (Zapalote Chico x CMS 14C) and 4.35 for crosses between susceptible populations (CMS 01 x CMS 02).

Table 7. Maize genotypes showing tolerance to FAW at EMBRAPA/CNPMS.

Genotypes	Mean rating	Grain weight (g) Infested	Grain weight (g) Protected
Amarelo Sertão	6.9	2487	2125
CMS 21	6.6	2313	1962
Palha Roxa Mantena	6.2	2961	2534
CMS 04	6.1	3474	3174

Results obtained with 180 S_1 progenies of the MIRT population tested for resistance to the FAW showed a genetic heritability of 53% (superior limit) and 42% (low limit) (Viana and Guimaraes 1994), indicating a good range of genetic variability present in these materials which can be useful to a breeding program for resistance to this pest.

Conclusion

In summary, the plant resistance program to maize pests with emphasis on FAW and LCB at EMBRAPA/CNPMS has been focussed on the following aspects:

- Locating new and better sources of resistance.
- Properly maintaining the resistant genotypes.
- Determining the mechanisms and inheritance of resistance.
- Developing suitable breeding methodologies for incorporating genetic resistance in agronomically suitable cultivars.

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Table 8. Diallel cross of 10 population tested for resistance to FAW at EMBRAPA/CNPMS. 1990/91/92.

Genetic Material	Mean rating	SCA[1]	GCA[2]
Zapalote Chico	3.2		-0.56
Z. Chico x CMS 01	3.1	-0.06	
Z. Chico x CMS 02	3.3	0.27	
Z. Chico x CMS 05	2.4	-0.53	
Z. Chico x CMS 06	3.2	0.19	
Z. Chico x CMS 11	2.7	-0.30	
Z. Chico x CMS 14C	2.1	-0.90	
Z. Chico x CMS 15	2.1	-0.82	
Z. Chico x CMS 23	3.2	0.37	
Z. Chico x CMS 28	3.4	0.22	
CMS 01	4.2		0.19
CMS 01 x CMS 02	4.3	0.57	
CMS 01 x CMS 05	3.4	-0.33	
CMS 01 x CMS 06	3.5	-0.21	
CMS 01 x CMS 11	3.9	0.15	
CMS 01 x CMS 14C	3.7	-0.10	
CMS 01 x CMS 15	3.6	-0.11	
CMS 01 x CMS 23	3.1	-0.52	
CMS 01 x CMS 28	3.9	0.02	
CMS 02	3.5		0.57
CMS 02 x CMS 05	3.7	0.16	
CMS 02 x CMS 06	3.4	-0.23	
CMS 02 x CMS 11	3.7	0.03	
CMS 02 x CMS 14C	3.4	-0.21	
CMS 02 x CMS 15	3.7	0.12	
CMS 02 x CMS 23	3.2	-0.24	
CMS 02 x CMS 28	3.6	-0.19	
CMS 05	3.4		0.01
CMS 05 x CMS 06	3.4	-0.13	
CMS 05 x CMS 11	4.0	0.38	
CMS 05 x CMS 14C	3.1	-0.46	
CMS 05 x CMS 15	3.9	0.42	
CMS 05 x CMS 23	3.7	0.26	
CMS 05 x CMS 28	4.1	0.41	
CMS 06	3.7		0.04
CMS 06 x CMS 11	3.1	-0.50	
CMS 06 x CMS 14C	3.5	-0.10	
CMS 06 x CMS 15	3.7	0.14	
CMS 06 x CMS 23	4.0	0.53	
CMS 06 x CMS 28	3.8	0.02	
CMS 11	3.9		0.08
CMS 11 x CMS 14C	3.6	-0.04	
CMS 11 x CMS 15	4.0	0.40	
CMS 11 x CMS 23	3.6	0.14	
CMS 11 x CMS 28	3.1	-0.67	
CMS 14C	4.0		0.08
CMS 14 x CMS 15	3.6	0.00	
CMS 14 x CMS 23	3.7	0.24	
CMS 14 x CMS 28	4.6	0.84	
CMS 15	3.6		-0.01
CMS 15 x CMS 23	3.3	0.13	
CMS 15 x CMS 28	3.4	-0.28	
CMS 23	3.0		-0.01
CMS 23 x CMS 28	3.5	-0.09	
CMS 28		3.8	0.21
Avg.	3.5		
LSD (0.050)	0.9		
Dp (G_i - G_i)			0.13
Dp (S_{ij} - Skl)		0.43	

1 SCA Specific combining ability.
2 GCA General combining ability.

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